

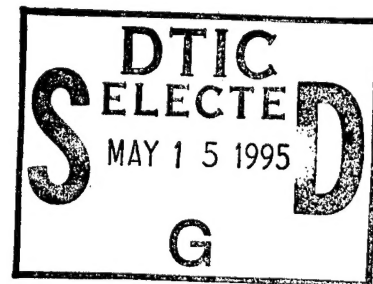
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PROGRAMMABLE REAL-TIME OPTOELECTRONIC HYBRID
THRESHOLD LOGIC PROCESSORS

by

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NAIC-ID(RS)T-0415-94 5 April 1995

MICROFICHE NR: 95C000156

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English pages: 11

Source: Zhongguo Jiguang, Vol. 18, Nr. 10, October 1991;
pp. 760-764

Country of origin: China

Translated by: SCITRAN

F33657-84-D-0165

Requester: NAIC/TATE/Capt Joe Romero

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PROGRAMMABLE REAL-TIME OPTOELECTRONIC HYBRID THRESHOLD LOGIC PROCESSORS

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Liu Shutian Wu Jie Li Chunfei

Abstract

A programmable real-time optoelectronic hybrid threshold logic processor is presented and the applications of the processors in question to digital optical computing a digital optical signal processing are discussed.

Key Words: threshold logic, optical computing, optoelectronic hybrid logic circuit

I. INTRODUCTION

In optical computing research, optical nerve networks simulating human brain nerve logic handling processes is attracting the greatest attention [1]. Because of the fact that human brain logic processing possesses a high degree of parallelism, vagueness, multiple values, weighing, the adopting of thresholds, feedback, and a lot of similar characteristics, the result is that it is very necessary to explore using optical methods to realize logic which possesses even stronger performance than vertex primitives such as fuzzy logic, multiple value logic, binary as well as multiple value threshold value logic. In recent years, people have already, in different optical systems, realized optical multiple value logic operations [2-4]. Although Arrathoon, et al, have made recommendations for

* Numbers in margins indicate foreign pagination.
Commas in numbers indicate decimals.

the use of wave guide methods to realize optical threshold logic [5], up to the present time, however, there are still very few simple methods for realizing optical threshold value logic. This article, for the first time, puts forward a type of optoelectronic hybrid threshold value logic processing device constructed making use of light emitting diodes (LED) as well as optoelectronic triodes (PD). The processing device in question is capable of carrying out, by optical signals, programmable, real-time control. In conjunction with this, it is possible to obtain two types of weighted values and threshold values, that is, weighted values and threshold values are all capable of being positive or negative. The result of this is that the logic processing devices in question, in and of themselves, compose one complete logic set. The structure of this type of logic processing device is simple, has good reliability, and, even more important, it is compatible with current very large scale integration electronics (VLSI). It is capable, on GaAs base chips or GaAs/Si base chips, of carrying out optoelectronic-microelectronic hybrid integration. As a result, there is hope for applications in optical computing as well as digital optical information processing.

II. OPTOELECTRONIC HYBRID THRESHOLD LOGIC PROCESSING DEVICES

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What Fig.1 shows is a threshold logic gate schematic diagram. It has n individual binary system input variables x_i ($i = 1, 2, \dots, n$). Each variable is accompanied by a correlated weighing w_i ($i = 1, 2, \dots, n$). Output y and an anticipated threshold value T have the relationship below [6]:

$$y = \begin{cases} 1, & \text{当 } \sum_{i=1}^n w_i x_i \geq T; \\ 0, & \text{当 } \sum_{i=1}^n w_i x_i < T. \end{cases} \quad (1)$$

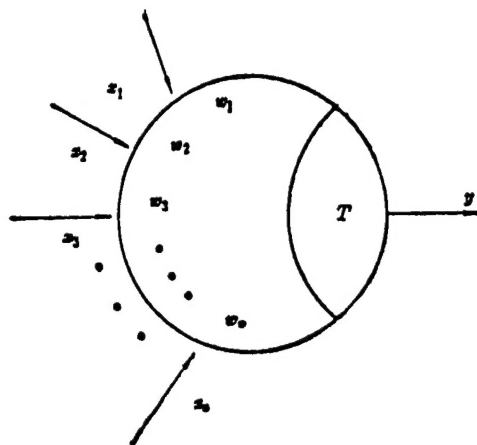


Fig. 1 Schematic diagram of threshold gate

It is only when the sum of input variable weighing is larger than or equal to threshold values that output y is 1. Otherwise, it is 0. If a switching function $f(x)$ is a threshold value logic function, that is, it is possible to produce with a single threshold value logic gate, in that way, it is always possible to find a weighing-threshold integration $\{w_1, w_2, \dots, w_n; T\}$ to make it satisfy equation (1). Mathematically, if $\{w_1, T\}$ is selected as a value in the set of whole real integers, then, an individual threshold value logic gate forms a complete logic set. That is, all logic functions are capable of being completed from finite single threshold gates. In addition, threshold value logic gates possess greater amounts of input than do binary system elements. The result of this is that it is possible to very greatly reduce the numbers of logic units and transmission lines. Fig.2(a) is a circuit diagram of an optoelectronic hybrid threshold logic processing device. In reality, it is a variation of a bistable light emitting diode circuit [4]. In experiments, we took optical feedback and eliminated it in order to quicken logic gate response speeds. Light emitting diode output acts as logic gate output y . Each weighted input terminal includes 4 silicon optoelectronic triodes connected in series. Among these, two are input variable input terminals. Moreover, besides these, two are weighted signal input terminals. Each weighing w_i is respectively divided into two parts: w_{i+} and w_{i-} . When w_i is a positive weighing, $w_i = w_{i+}$, and $w_{i-} = 0$. If x_i is negatively

weighted, then $w_i = -w_i^-$, and $w_i^+ = 0$. Threshold values T are also controlled by two light emitting triodes connected in series with each other. In the same way, they possess two positive and negative values. Light strengths changing weighing and threshold value signals are then capable of arriving at different weighing and threshold values. Thus, it is possible to carry out real time programmable control of the threshold logic processing devices in question.

In order to explain how weighing and threshold values are realized in association with the logic processing devices in question, we take a time when there is only one variable input x_i as an example. See Fig.2(b). Input x_i is incident on PD_i^+ and PD_i^- . Moreover, weighing control signals w_i^+ and w_i^- are respectively incident on $PD^+_{w_i}$ and $PD^-_{w_i}$. Current strength I_{di} can be written as

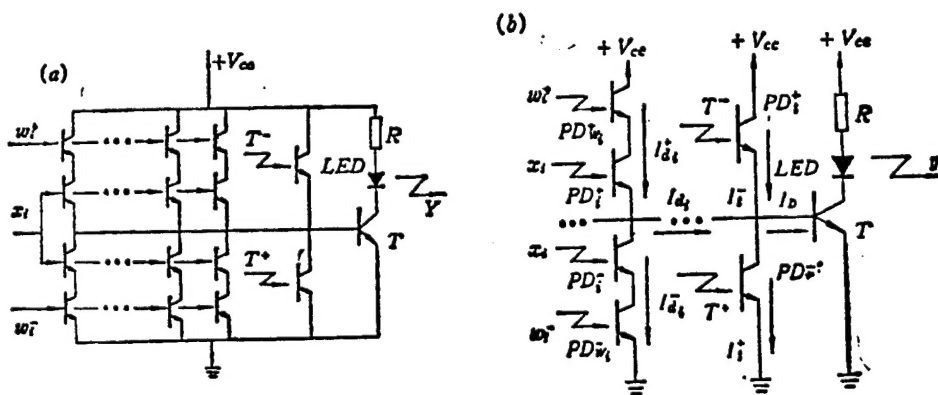


Fig. 2 (a) Circuit of optoelectronic threshold logic processor; (b) A part of the circuit of Fig. 2 (a) which only consists of input x_i

$$I_{di} = I_{di}^+ - I_{di}^-$$

(2)

Assuming all optoelectronic triodes are the same, and, moreover, operations are in a linear amplification zone, then, optoelectronic output current I_d forms a direct proportion with input light strength P_i , that is, $I_{di} = KP_i$. In this, K is an optoelectronic transfer constant. Due to the fact that optoelectronic triode PD_i^+ and PD_{wi}^+ (PD_i^- and PD_w^-) are connected in series to each other, then $I_{di}^+(I_{di}^-)$ only form a direct proportion with the smallest among light strengths associated with signals x_i and w_i or minus. That is,

$$I_{di}^{\pm} = K \min(P(x_i), P(w_i^{\pm})) \quad (3)$$

In this, $\min(x)$ is minimum value function. $P(x_i)$ and $P(w_i^+$ or minus) are respective light strengths associated with x_i and w_i^+ or minus. The weighing and threshold value methods which we realized were different in taking logic variable amplitude values and multiplying a factor w_i . From equation (3), we saw that, if $P(w_i^+$ or minus) is far smaller than light strength amplitude values when $x_i = 1$, then, when $x_i = 1$, I_d^+ or minus is only related to $P(w_i^+$ or minus). That is, one has the expressions below:

$$I_{di}^{\pm} = \begin{cases} KP(w_i^{\pm}), & \text{for } x_i = 1 \\ 0, & \text{for } x_i = 0 \end{cases} \quad (4)$$

Thus, with $P(x_i)|_{x_i=1} \gg P(w_i^{\pm})|_{w_i^{\pm}=1}$, we are able to make $P(x_i)|_{x_i=1} = qP(w_i^{\pm})|_{w_i^{\pm}=1}$. That is, take light strength amplitude values when $x_i = 1$ and divide them into q equal parts. If weighing values associated with x_i are $\pm r (1 \leq r \leq q)$, then $P(w_i^{\pm}) = rP(w_i^{\pm})|_{w_i^{\pm}=1}$. For example, when $x_i = 1$, $P(x_i) = 50$ micro Watts. Moreover, when w_i^+ or minus = 1, $P(w_i^+$ or minus) = 5 micro Watts. By contrast, $q = 10$. If it is necessary, for x_i , to select a weighing value to be 5, then,

light strengths associated with w_i^+ signals are 25 micro Watts. Of course, at this location, the numerical value of q can be selected as anything. However, it requires that $P(w_i^+)|_{w_i^+=1}$ must be larger than triode saturation threshold value light strengths. Generally, this saturation threshold value is very small--approximately 0.5 micro Watt. The result is that weighing values can be selected within very large ranges..

Assume that, in Fig.2(a), there are m individual positive weighted inputs and $n-m$ individual negative weighted inputs. In that case, after going through the selection of threshold values, electric currents are

$$I_d = \sum_i^n K \min\{P(x_i), P(w_i^+)\} - \sum_{j=1}^{n-m} K \min\{P(x_j), P(w_j^-)\} \pm KP(T) \quad (5)$$

Here, when plus or minus $KP(T)$ is selected as a negative value, $T = T^+$. When positive values are selected, $T = -T^-$. Giving consideration to the influences of such minimum saturation threshold value light strengths as those described above, threshold value light signal strength $P(T)$ is capable of being adjusted to be $P(T^+) = P(T) - 0.5$ micro Watt and $P(T^-) = P(T) + 0.5$ micro W. This, in fact, corresponds to the addition, on PD_t^- , of a constant sustained light signal H in order to overcome saturation threshold value light strengths. At this time, threshold value logic output is $y = 1$. Moreover, only for $I_d \geq 0$. Selecting different weighing and threshold values, it is possible to obtain various types of logic functions.

Fig.3 (a) - (f) are experimental results when input variable number $n = 3$. In experiments, input signals are provided by light emitting diodes associated with three synchronous square wave voltage signal drives directly connected and produced by signal generators. The peak

voltage value is 10V. The current limiting resistance is 220 ohms. Weighing signals w_i^+ or minus and threshold values T are also supplied by light emitting diodes.

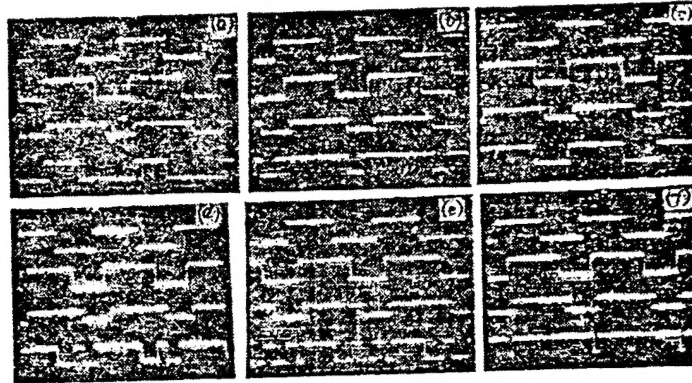


Fig. 3. Experimental results for input variables number $n=3$, the upper three waveforms indicate x_1 , x_2 and x_3 , respectively; the bottom waveform shows the output Y
 (a) AND; (b) OR; (c) MAJORITY; (d) $f(x) = x_1 + \bar{x}_2 x_3$; (e) $f(x) = x_1 x_3 + \bar{x}_2 (x_1 + x_3)$;
 (f) $f(x) = \bar{x}_1 + \bar{x}_2 + x_3$

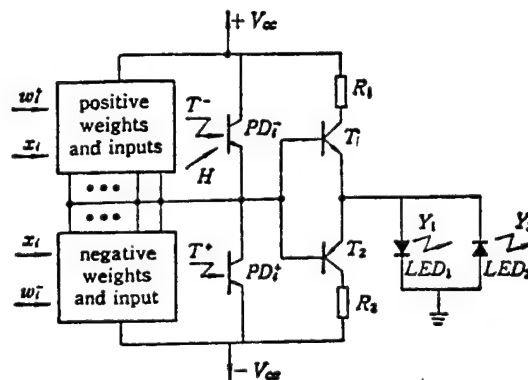
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They go through changeover switching and changing variable resistance in order to change the positive and negative amplitudes. Drive source voltage and the main circuit are both $V_{cc} = 4.5$ V. Series connected resistances corresponding to when $w_i = 1$ and 2 are, respectively, 1.2 kilo ohms and 600 ohms. Fig.3(a) and (b) are and or logic obtained when $w_i = 1$ and T is taken respectively as 1 and 3. Fig.3(c) is MAJORITY logic obtained when $w_i = 1$ and $T = 2$. When two or more of x_1 , x_2 , x_3 are 1, the output is 1. In the same way, when $w_i = -1$ and $T = -2$, we also obtain MINORITY logic. Obviously, it is only at times when input weighings are different that it is possible to obtain even more abundant logic functions. For example, with regard to weighing-threshold set $\{2, -1, 1; 1\}$, it is possible to produce $f(x) = x_1 + \bar{x}_2 x_3$. With regard to $\{1, -1, 1; 1\}$, it is possible to produce $f(x) = x_1 x_3 + \bar{x}_2 (x_1 + x_3)$. Moreover, with regard to $\{-1, -1, 1; -1\}$, it is, then, possible to produce $f(x) = \bar{x}_1 + \bar{x}_2 + x_3$. See Fig.3(d) - (f). The experimental results above are only a small portion of the logic functions a

single threshold value logic gate is capable of obtaining. It should be pointed out that, in Fig.3(a) - (f), three input signal composites only give 6 types out of all 8 types of composites. The two types of composite forms (0,1,0) and (1,0,1) are not included. However, as far as input signals are concerned, this type of arrangement form is still capable of giving the most common forms associated with all composite situations. Thus, it is possible to recognize that results associated with Fig.3(a) - (f) directly reflect logic operation truth tables.

Fig. 4 Schematic diagram of threshold logic processor with double output Y_1 and Y_2 , where

$$Y_1 = f(x) \text{ and } Y_2 = \overline{f(x)}$$



One individual threshold value logic gate is capable of possessing numerous individual binary system outputs Y_1, Y_2, \dots, Y_m . In situations with the same weighing, each individual output terminal gives different threshold values. This requires taking input weighing and reproducing them to become m parts. When threshold values are added, it requires that they do not influence each other. The circuit in Fig.4 is one which possesses two output special cases. It has two amplifying triodes. The output characteristics are just opposite to each other. One is the NPN triode T_1 . Moreover, besides that, one is the PNP triode T_2 . Use is made of two light emitting diodes LED_1 and LED_2 to act as the output terminals. $-V_{cc}$ is the negative bias voltage. With regard to the output of LED_2 , it is only when there is negative weighted input and it is larger than negative threshold values that it is possible to have the result be

1. Theoretically, when $\sum_{i=1}^n w_i x_i = T$, the two circuit outputs y_1 and y_2 should both be 1. At this time, if the weighing-threshold set associated with output y_1 is $\{w_1, w_2, \dots, w_n; T\}$, then, the weighing-threshold set corresponding to y_2 is $\{-w_1, -w_2, \dots, -w_n; -T\}$. However, due to the cut-off characteristics of triodes T_1 and T_2 and also the inability to simultaneously add corrections to an individual threshold value, that is, it is only possible to add correction H to T^- or T^+ input terminals, the result is simply that y_1 and y_2 outputs exist opposite to each other, that is, $y_1 = \bar{y}_2$. If one takes the threshold value offset associated with H sustained light and eliminates it, then there will also exist a condition of $y_1 = y_2 = 0$. In discussions, we also want to analyze applications associated with logic devices having this type of structure.

III. DISCUSSION

Threshold value logic is not only an effective method associated with realizing logic functions in multiple variable Boolean algebra. Moreover, it also has broad applications with regard to all such areas as numerical pattern processing, form recognition, fuzzy function classification, as well as nerve networks, and so on. Optical nerve network models at the present time--for example, Hopfield models [7]--are dependent, in fact, on threshold value logic. Reciprocally weighted feedback input between all the various individual neurons certainly pick thresholds to output. Only then is it possible to completely and simply associate such functions as memory and learning [8]. The result is that threshold value logic is capable of being directly applied to nerve network research. In reality, Fig.2(b) can be seen as a simple optoelectronic hybrid neuron. It can cause EXCITATORY weighted input and INHIBITORY weighted input directly reducing each other. The

result is that the neuron in question, in and of itself, possesses threshold selection functions. In comparison, the electronic devices and electronic computers needed to select thresholds in nerve networks seem excessively complicated. Besides this, the neurons in question also are capable of possessing +1 or -1 BIPOLAR BINARY OUTPUT (see Fig.4). Very large scale integration technology and free spatial optical interconnection technology will cause this type of neural network model to attract even more people.

Two dimensional parallel logic processing is also one important topic associated with optical computing research [9]. Optical threshold logic, in the same way, has hopes for applications to the realms in question. As far as the two variable input threshold value logic processing devices of which Fig.4 is the structure is concerned, in cascade, an individual or gate is then capable of completing 16 types of Boolean logic functions. Generally speaking, y_1 is capable of completing 14 types of logic besides XOR and NXOR. If, in Fig.4, one takes the threshold value offset and eliminates it, that is, allowing a state of $y_1 = y_2 = 0$ to exist, outputs y_1 and y_2 --when $w_1 = 1$, $w_2 = -1$, $T = 0$ --respectively give the relationships $x_1 \cdot \bar{x}_2$ and $\bar{x}_1 \cdot x_2$. The result is that, after adding in one individual or gate cascade, the or gate output $y = y_1 + y_2$ directly gives XOR logic. In the same way, when $w_1 = w_2 = 1$, $T = 1$, y directly gives NXOR logic. This type of single logic processing device is capable of acting as one logic unit (PIXEL) in two dimensional parallel logic processing. It is capable of directly, by optical signal control, realizing real time, programmable space-invariant and space-variant logic processing.

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